6   MPLS Model User Guide

Multi-Protocol Label Switching (MPLS) is a multi-layer switching technology that uses labels to determine how packets are forwarded through a network. The first part of this document describes key features of the MPLS specialized model and the second part focuses on procedures for configuring MPLS in your network model.

Model Features

This section contains a list of the main features available in the Multi-Protocol Label Switching model:

* The MPLS model captures the following protocol behavior:

Table 6-1   MPLS Model Features

Feature	Description
LSP (Label Switched Path) configuration	• LSPs can be created manually or automatically from traffic conversation pairs. • LSPs are easily reused in other scenarios or projects by using the LSP import and export features. • Both dynamic and static LSPs are created using the path object.
Differential Services (DiffServ)	• DiffServ extensions, as defined in RFC-2475, are provided. • The model enables you to perform QoS (quality of service) analyses by accounting for different types of service.
Traffic Engineering	Traffic engineered routes are computed using Constrained Shortest Path First (CSPF) with OSPF or IS-IS routing protocols.
End of Table 6-1	

- MPLS models are implemented based on information available from the following sources.

Table 6-2　Reference Documents

Model Features	Document
Traffic Engineering	
MPLS TE	RFC-2702—Requirements for Traffic Engineering Over MPLS
FECs	RFC-3031—Multiprotocol Label Switching Architecture
IGP shortcuts	draft-hsmit-mpls-igp-spf-00
Label Switched Paths	
Dynamic LSPs Static LSPs	RFC-3031—Multiprotocol Label Switching Architecture
LSP routing	
OSPF TE IS-IS TE	RFC-2676—QoS Routing and OSPF Extensions
Label distribution	
LDP	RFC-3036—LDP Specification
CR-LDP	RFC-3212—Constraint-based LSP Setup Using LDP
RSVP-TE	RFC-3209—RSVP-TE: Extensions to RSVP for LSP Tunnels
PP-VPNs	
A framework for layer-3 PP VPNs	RFC-2547—BGP/MPLS VPNs
BGP/MPLS VPNs	draft-ietf-ppvpn-framework-05
Quality of Service	
QOS Architecture	RFC-2475—An Architecture for Differentiated Services
MPLS Support of Differentiated Services	RFC-3270—Multi Protocol Label Switching draft-ietf-mpls-diff-ext-08
Restoration and Resiliency	
Fast reroute with bypass tunnels LSP protection with ingress backup	draft-ietf-mpls-rsvp-lsp-fastreroute-00
End of Table 6-2	

Node Models

The MPLS model suite supports workstation, server, router, and link models from the standard model library. The LER (Label Edge Router) and LSR (Label Switching Router) node models in the MPLS object palette are preconfigured to support MPLS. However, you can configure any of the router models in the standard model library to model LERs and LSRs.

**Figure 6-1   MPLS Object Palette**
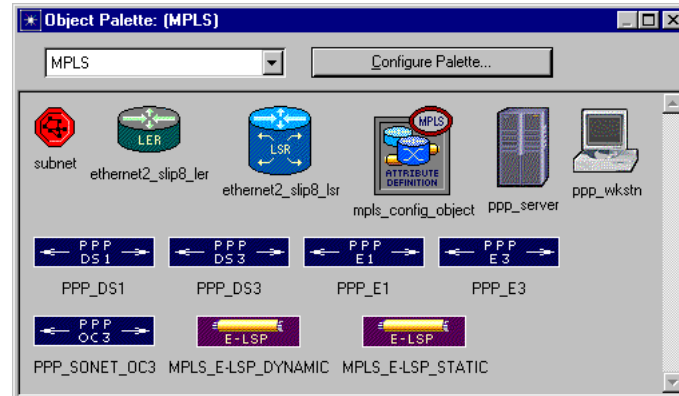
Model Attributes

Global MPLS attributes, which are used to configure network-wide MPLS parameters, are grouped in the MPLS configuration object. Router-specific MPLS attributes are grouped in the MPLS Parameters attribute on each router. They are described in <u>Router Attributes</u> on page SPM-6-6.

MPLS Configuration Object Attributes

Some of the important MPLS configuration object attributes are described below.

- **FEC Specifications** This attribute specifies the Forwarding Equivalence Class (FEC) parameters used by MPLS in the network. FECs classify and group packets so that all packets in a group are forwarded the same way. FECs are based on any of the IP header fields—ToS, Protocol, Source Address Range, Destination Address Range, Source Port, and Destination Port can all be used to define a FEC. Figure 6-2 <u>Specifying FEC Attributes</u> on page SPM-6-4 shows the attribute sequence for defining an FEC.

Figure 6-2　Specifying FEC Attributes
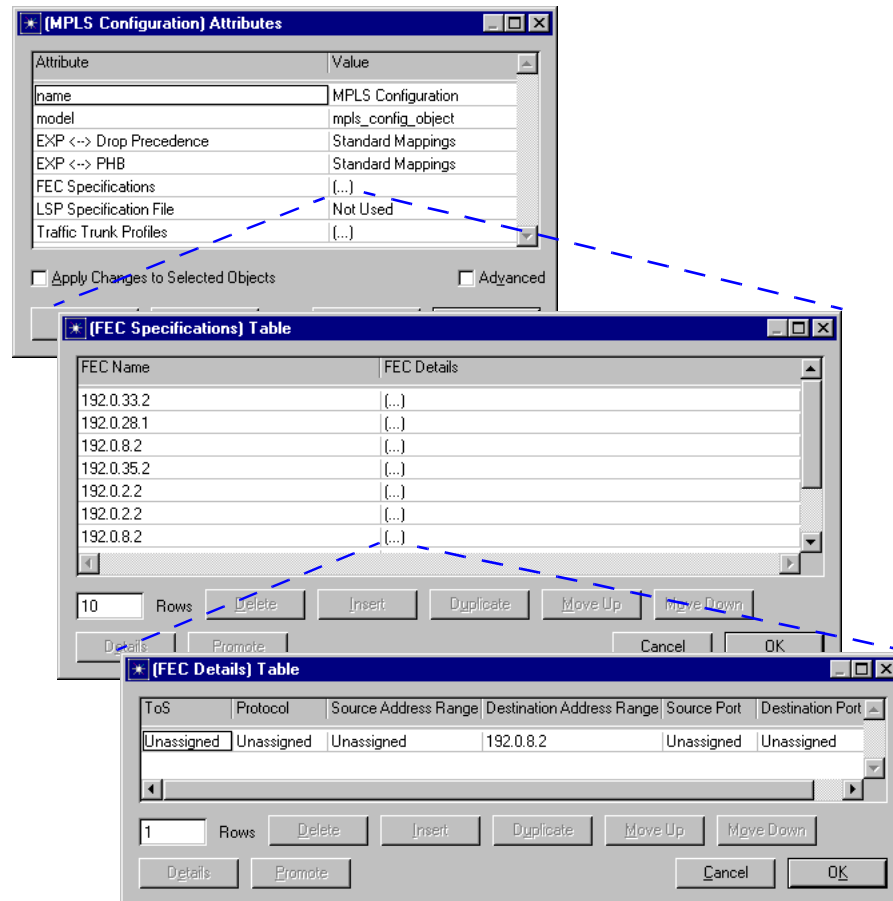
The FEC Details Table helps define the FEC through a set of match rules, which are combinations of TCP, UDP, and IP header fields. FECs are determined by taking a logical AND of the column settings in a row and by taking a logical OR of each of the rows. In other words, for a packet to qualify for a particular FEC, the IP header fields must satisfy every condition of at least one row of the defined FEC. For example, a FEC that consists only of email and ftp traffic would be specified as shown in Figure 6-3.

Figure 6-3　FEC Details for E-mail and FTP Traffic
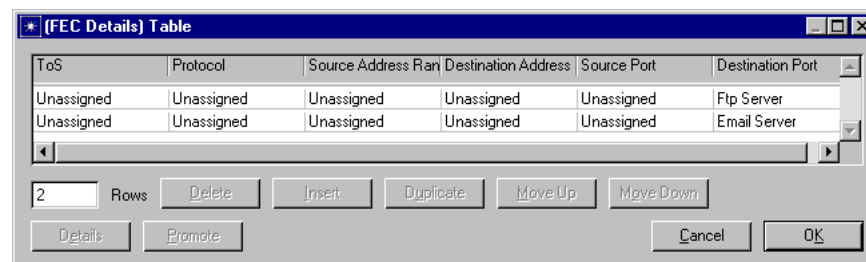
Therefore, if the IP header of a packet contained either email or FTP, it would qualify for the FEC defined in Figure 6-3, and would be sent over the corresponding LSP.

- **LSP Specification File** This attribute indicates whether the network LSPs should be configured according to the text file specified. You can update the text file by clicking OK in the LSP Browser. Updating the file recreates the file based on the current network LSP settings, including LSPs that might not have been in the original file (such as those created manually).

- **Traffic Trunk Profiles** This attribute specifies out-of-profile actions and traffic classes for traffic trunks in the network. Traffic trunks capture traffic characteristics such as peak rate, average rate, and average burst size. The default Trunk Details setting configures a trunk with a value of 32,000 bits/sec for maximum and average bit rate and 32,000 bits for maximum burst size.

Figure 6-4   Specifying Traffic Trunk Profiles
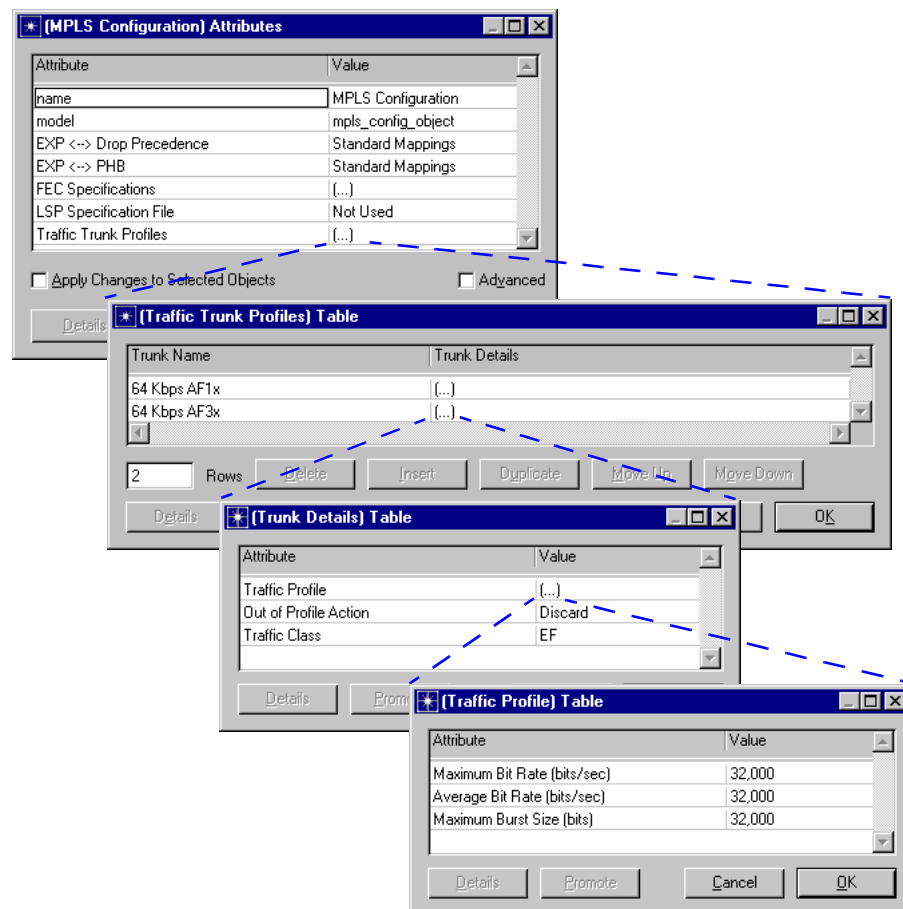
- **EXP <--> Drop Precedence** and **EXP <--> PHB** These attributes specify how EXP bits in the MPLS shim header are translated into diffserv information at each LSR. For E-LSPs, LSRs determine Per Hop Behavior (PHB), while on L-LSPs, they determine Drop Precedence. Use the default setting unless you are analyzing the effects of QoS.

Figure 6-5   Mapping EXP Bits to Drop Precedence and PHB
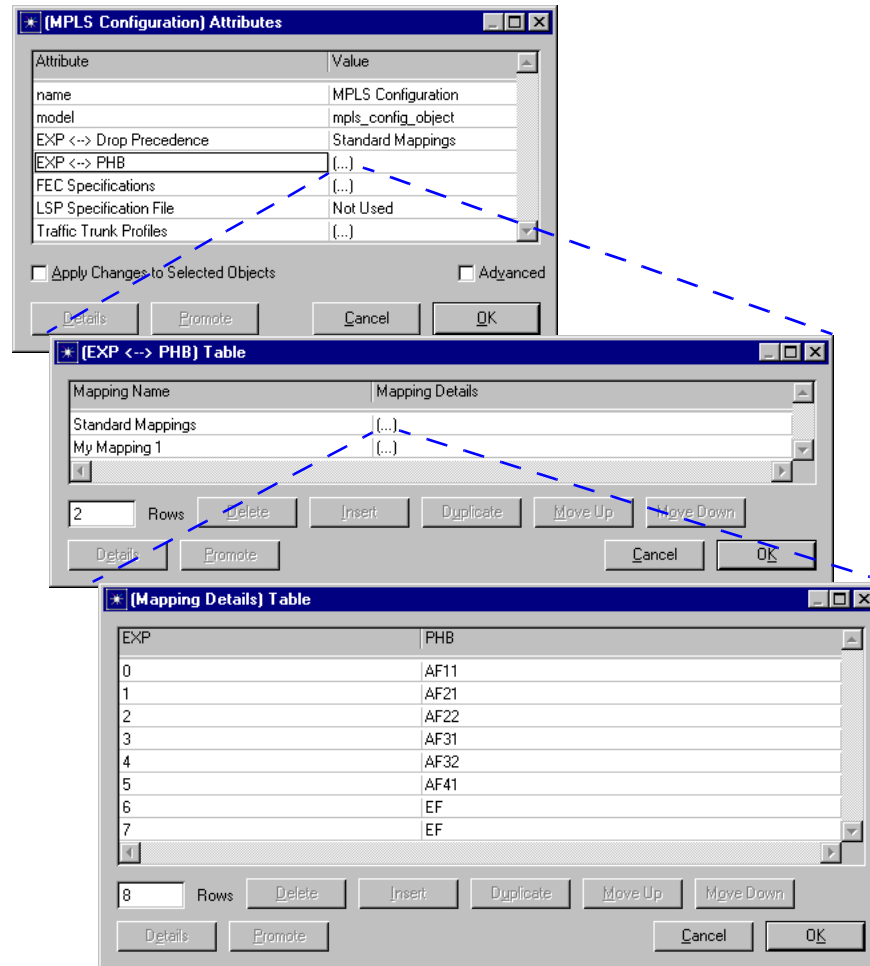
Router Attributes

Some of the important MPLS Parameters attributes set on routers are described below.

Traffic Mapping Configuration

This attribute specifies bindings between FECs and LSPs. Each row of the Traffic Mapping Configuration table specifies a distinct traffic engineering (TE) binding. Each TE binding specifies the FEC, traffic trunk, and LSP that is applied to the label of the incoming packet.

Only previously defined values appear in the attribute pull-down lists. If no values appear in the attribute pull-down lists, verify that you have defined the FECs and traffic trunks in the MPLS Configuration object, and that the LSPs appear in the network path browser.

When an unlabeled packet arrives at an ingress LER, the following sequence occurs to determine the correct label for the packet:

1) The TE binding is selected based on the packet FEC and the incoming interface.

2) The packet is checked to make sure that its traffic characteristics conform to those specified for the TE binding's traffic trunk.

3) The packet is labeled for and sent through the primary LSP specified for the TE binding.

Figure 6-6   Configuring TE Bindings

This weight attribute configuration uses LER2-LER5 75% of the time and LER2-site9 25% of the time.
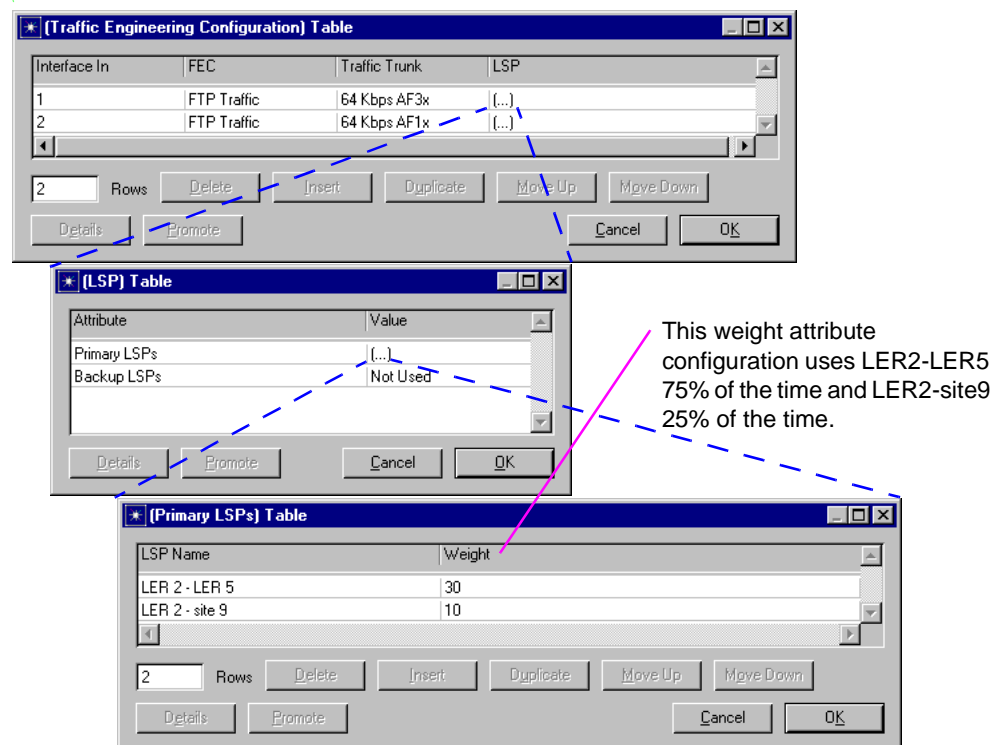
- **EXP <--> Drop Precedence** and **EXP <--> PHB** These attributes specify which mappings, defined in the MPLS configuration object, are used by the router.

- **LDP Parameters**—specifies Label Distribution Protocol parameters used by the LSR. LDP Parameters is a compound attribute, composed of the following sub-attributes:

  — **Discovery Configuration**—specifies Hello message parameters needed to learn of neighboring routers

  — **Session Configuration**—specifies Keep-alive message parameters used to establish LDP sessions

  — **Recovery Configuration—**specifies how node and link failures are detected

Figure 6-7 Configuring LDP Parameters
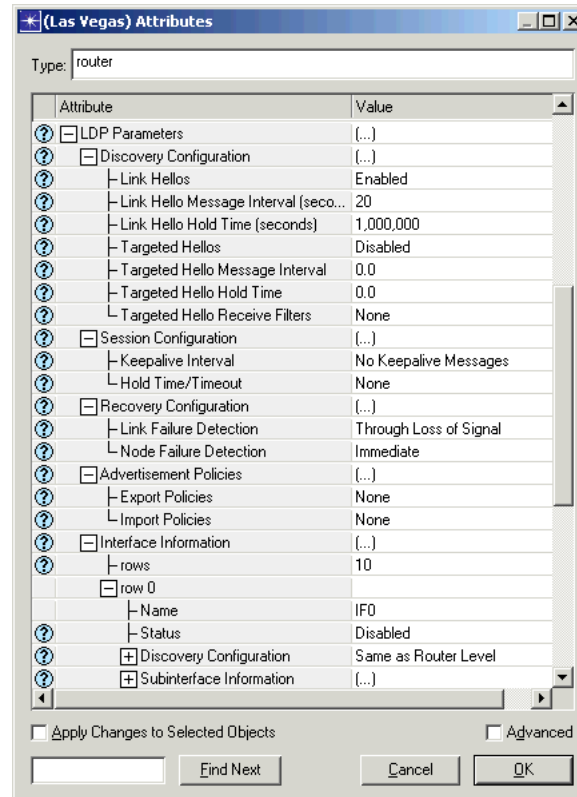

Simulation Attributes

The following simulation attributes are available (Configure/Run Discrete Event Simulation dialog box) when using the MPLS model suite.

- **CR-LDP Routing**—specifies if CR-LDP routing uses CSPF or conventional IGP to determine routes in loosely defined LSPs. The default value is IGP.

- **CSPF Retry Timer**—specifies how long an ingress LER waits after detecting a node or link failure before rerouting an LSP that traverses the failed node or link. The default value for this attribute is 45 seconds.

- **LDP Discovery End Time—**specifies when LDP discovery ends. After this time, no more LDP discovery packets are sent through the network. This value should occur after the network reaches a final, constant state in the simulation since no network topology or device status changes are reflected in the LDP routing tables after LDP Discovery End Time.

- **LDP Discovery Start Time**—specifies when LDP starts sending discovery packets through the network. Set this attribute to a value other than Do Not Start to enable LDP.

- **LSP Signaling Protocol**—specifies whether dynamic LSPs are signaled using CR-LDP (constraint-based routed LDP) or RSVP. The default value is CR-LDP.
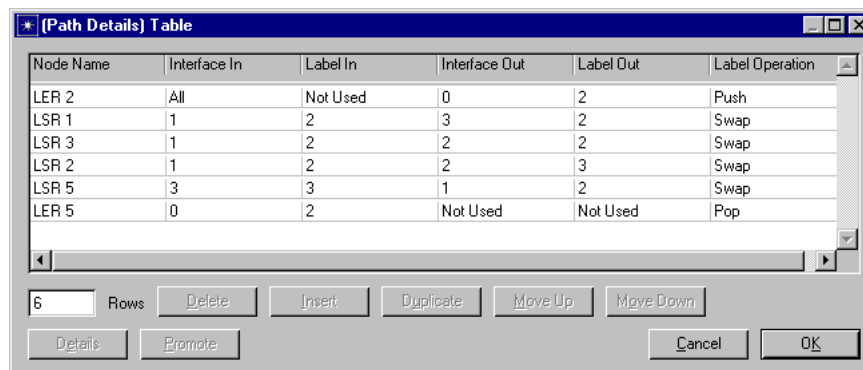
LSP Attributes

Some of the important LSP attributes are described below. Most of these attributes can also be configured in the LSP browser, which is described in the next section.

Figure 6-8   Configuring an LSP's Attributes
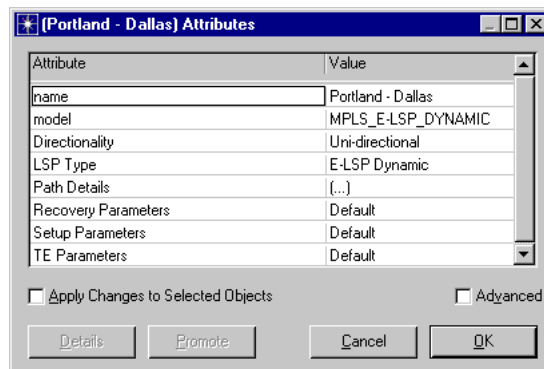
- **Directionality**—specifies if an LSP is unidirectional or bidirectional. Dynamic LSPs are always unidirectional.

- **LSP Type**—specifies whether the LSP is of type E-LSP or L-LSP. For E-LSP, three experimental bits in the shim header carry the Diff-Serv information. This provides eight different types of service (TOS) per LSP. For L-LSP, TOS information is contained in the MPLS label and all packets traversing the link are treated equally.

- **Path Details**—specifies which packets use the LSP and defines how packets are forwarded through the LSP. This attribute is automatically configured for dynamic LSPs. To configure this attribute for static LSPs, select Update LSP Details from the Protocols > MPLS menu.

Figure 6-9   Path Details for a Static LSP

- **Recovery Parameters**—specifies recovery parameters that are used to reroute traffic on this LSP if there is a link or node failure along the LSP.

Figure 6-10　Recovery Parameters Configuration

• **Setup Parameters**—specifies the duration of the LSP.

Figure 6-11　Setup Parameters Configuration

• **TE Parameters**—specifies the traffic engineering constraints used by CR-LDP to find a route through the network. CR-LDP uses Constrained Routing to find the route that is the best fit for the specified constraints. This attribute applies to dynamic LSPs only. Make sure you account for network bandwidth availability when configuring static LSPs.

**Figure 6-12　TE Parameters Configuration**

LSP Browser

After you create the LSPs in the network, you may want to edit or view the default settings. You do this in the LSP browser, which you can access from the Protocols > MPLS > Browse/Edit LSP Information... menu item. The browser enables you to

• Set the hop type of LERs

• Set the start and end times for the LSP

• Set threshold values for bandwidth, delay, and hop counts in the LSP

• Hide some or all of the LSPs from view in the Project Editor workspace

• Export LSP configuration details to a file

Figure 6-13   Using the LSP Browser

This column indicates if the attribute values shown are from the GUI or the LSP specification file.

These attributes set the LSP's Path Details and Setup, TE, and Recovery Parameters attributes.
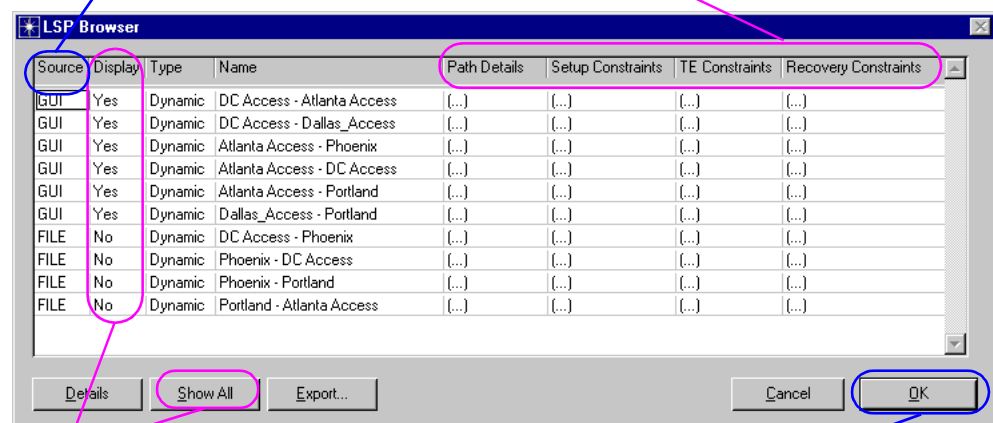
Clicking here toggles the display settings—the workspace is immediately refreshed to show or hide the LSPs.

Clicking OK saves the current settings in the LSP specification file or creates this file if one does not yet exist.

Available Statistics

To analyze MPLS performance, you can collect path statistics on end-to-end delay, utilization, and the amount of traffic on the LSP. These statistics can be collected on a per-flow or per LSP basis, where flows are individual flows of traffic within an LSP.

Figure 6-14   Selecting Statistics to Collect
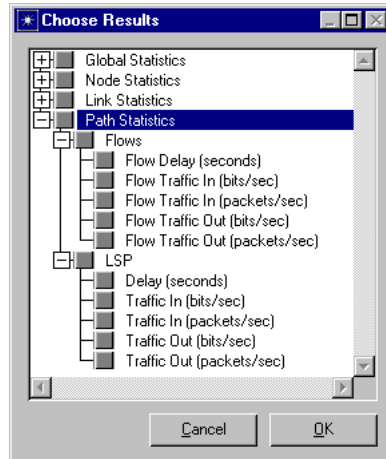
When analyzing your MPLS network, you may also want to look at the routes used for the LSPs. You can do this by selecting the Protocols > MPLS > Display LSP Routes... menu item.

Configuring MPLS in a Network

Configuring MPLS in a network is a three-step process. Before you can run a simulation using MPLS, you must

1) Create LSPs in the network topology

2) Create FECs and traffic trunks in the MPLS Configuration object

3) Configure LERs to direct packets into the appropriate LSPs

After this basic configuration is in place, you can add QoS/differentiated services (DiffServ) constraints or traffic shaping parameters.

Creating LSPs

After you create your network topology, you can add LSPs to the network. There are three methods of adding LSPs to your network:

- From traffic conversation pairs

- By drawing the LSPs in the Project Editor workspace

- From text files

The Update LSP Details operation creates traffic profiles and forward equivalence classes (FECs) for the LSPs, which you can modify later as you fine-tune your model.

The model supports both static and dynamic LSPs using the strict and loose path objects in OPNET. To create LSPs, use the standard procedure for creating paths as described in the Building Models chapter of the *User Guide* manual (Guru product documentation) or the Communication Mechanisms chapter of the *Modeling Concepts* manual (Modeler documentation).

You can create dynamic LSPs automatically using the Create LSPs From Traffic Conversation Pairs utility or manually using the standard procedure for creating path objects.

The Create LSPs From Traffic Conversation Pairs utility creates LSPs quickly based on some or all of the traffic conversation pairs in the network.

Procedure 6-1   Creating Dynamic LSPs from Demands

1 From the Protocols > MPLS menu, choose Configure LSPs from Demands.

➥ The Assign IP Addresses dialog box appears.

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2 If you have not assigned IP addresses to all connected interfaces in the network, click the "Perform Auto-Assignment" button. Otherwise, click the "Skip Auto-Assignment" button.

➥ The MPLS Configuration dialog box opens.

This box shows all the traffic pairs configured in the network with suggested configuration for LSP configuration.

3 In the MPLS LSP Configuration dialog box, specify which traffic conversation pairs should not generate LSPs by changing their Create LSP? fields to "No".

4 Verify that the LSP configuration is correct for each LSP you would like to create.

5 Click the Export To Network button to create the LSPs in the network.

➥ The LSPs appear in the network

End of Procedure 6-1

To create dynamic LSPs manually, you must specify the end points (ingress and egress LERs) of the LSP. You can also specify one or more intermediate routers or links along the path. When a specific link is selected for the LSP path, that hop is marked as strict and the LSP is always set up through that link. Use this method to indicate that certain routers or links must be used when routing packets in an LSP. If a node or link on a dynamic LSP's route fails, the ingress LER automatically tries to find an alternate route. However, if the failed link or node is marked as strict, the entire LSP fails and the ingress LER diverts packets to the backup LSP, if one exists.

Procedure 6-2   Creating Dynamic LSPs Manually

1 Click on the MPLS_E-LSP_DYNAMIC object in the MPLS object palette.

2 In the project workspace, click on the LSP's ingress LER.

3 If the LSP must use certain routers or links, click on the intermediate routers or links that must be used. Be sure to click on the objects in the same order that they occur in the LSP.

4 Click on the LSP's egress LER.

5 Double-click in the project workspace to finish drawing the LSP.

6 If you are finished creating dynamic LSPs, right-click in the project workspace and select Abort Path Definition to exit path definition mode. Otherwise, draw the next dynamic LSP.

End of Procedure 6-2

Constrained OSPF (CSPF) is used to implement constraint-based routing of LSPs. You can configure dynamic LSPs to use constraint-based routing in the LSP's TE Parameters attribute by setting the Bandwidth, Delay, and Hop Count constraints. When using TE constraints, the model must be configured to use (CSPF) as follows:

• The CR-LDP simulation attribute must be set to CSPF

• The IP routing protocol must be set to OSPF (You can set the dynamic routing protocol to OSPF using the IP Dynamic Routing Protocol simulation attribute.)

With static LSPs, you can specify the exact route used by the LSP. Static LSPs allow more routing control, but offer less resiliency to node and link failures. For this reason, you should always specify at least one backup route when configuring static LSPs in your network.

Procedure 6-3   Creating Static LSPs

1 Click on the MPLS_E-LSP_STATIC object in the MPLS object palette.

2 In the project workspace, click on the LSP's ingress LER.

3 Click on the next link or router in the LSPs route.

➥ The tooltips indicate which links and routers can be added to the route. Hold the cursor over a link or router for details about adding it to the LSP.

4 Continue clicking on each link or router in the route until all have been added.

5 Right-click in the project workspace and select Finish Path Definition to finish drawing the LSP.

6 If you are finished creating static LSPs, right-click in the project workspace and select Abort Path Definition. Otherwise, draw the next static LSP.

7 From the Protocols > MPLS menu, choose Update LSP Details to configure label switching information on the LSP(s).

End of Procedure 6-3

Creating FECs and Traffic Trunks

The traffic engineering bindings that govern how packets are labeled and forwarded in a network use FECs and traffic trunks to classify packets. All of the FECs and traffic trunks in a network are defined in the MPLS configuration object.

Procedure 6-4   Creating FECs

1 Place an MPLS configuration object in the project workspace and open its Attributes dialog box.

2 Double-click on the value for FEC Specifications.

   ➥ The FEC Specifications Table appears.

3 Change the Rows value to the number of FECs you want to create.

4 For each FEC, assign a name, then double-click in the Details column to describe the FEC.

End of Procedure 6-4

To work correctly, the model requires that you set up at least one default traffic trunk. Additional trunks can be used to handle prioritized flows.

Procedure 6-5   Creating a Default Traffic Trunk

1 Place an MPLS configuration object in the project workspace and open its Attributes dialog box.

2 Double-click on the value for Traffic Trunk Profiles.

   ➥ The Traffic Trunk Profiles Table appears.

3 Change the Rows value to 1.

4 Specify a name for the trunk, such as Default Traffic Trunk.

5 Leave the Trunk Details attribute as "Default".

End of Procedure 6-5

This procedure can be modified to set up separate trunks for traffic of different priorities. To do this, double-click on the Trunk Details attribute and specify the appropriate values for each traffic trunk.

Creating TE Bindings on LERs

After you create the LSPs, FECs, and traffic trunks, you can create TE bindings that govern which packets are sent to which LSPs. You do this in the LER's MPLS Parameters ⬐ Traffic Mapping Configuration attribute.

Procedure 6-6   Creating a TE Binding

1 Open the LER's Traffic Mapping Configuration attribute dialog box (MPLS Parameters ⬐ Traffic Mapping Configuration).

2 Add a row to the table.

3 Click in the "Interface In" column and specify which interfaces the binding applies to in the Interface Binding Specification table. To select an interface, click in the Apply Binding column for that interface to toggle the value to "Yes."

➡ The interface(s) you selected appear in the Traffic Mapping Configuration dialog box. Note that the interface number for higher layers corresponds to the router's loopback interface.

4 Select a FEC for the binding from the FEC pull-down menu.

5 Select a traffic trunk for the binding from the Traffic Trunk pull-down menu.

6 Click in the LSP column to specify the primary and backup LSPs.

End of Procedure 6-6

Exporting LSP Configuration Details for Use in Other Scenarios

You can reuse LSPs that you have configured elsewhere by exporting the LSP configuration details to an ASCII file and using this file to create LSPs in the network.

Procedure 6-7   Exporting LSP Configuration to an ASCII File

1 From the Protocols > MPLS menu, choose Browse/Edit LSP Information....

➥ The LSP Browser appears.

2 Click Export to export the LSP configuration for all LSPs to a file.

➥ The Output File Name dialog box appears.

3 Specify a name for the file.

4 Click OK to perform the export.

➥ The file is saved in the primary models directory.

5 Click Cancel to close the LSP Browser.

End of Procedure 6-7

The exported file contains the attribute settings of all LSPs in the network. You can use the file as is in other scenarios, or you can modify the file to add, remove, or change LSPs. Notice that the LSP configuration file closely resembles the Path Details table for each LSP.

Procedure 6-8   Using an LSP Configuration File in a Scenario

1 Open the MPLS Configuration object's Attributes dialog box.

2 Select the LSP configuration file you wish to import from the LSP Specification File pull-down menu.

3 Click OK to close the Attributes dialog box.

➥ The LSPs are added to the scenario. By default, LSPs from files are not displayed in the network. To display these LSPs, open the LSP browser and set their Display attributes to Yes.

End of Procedure 6-8

If you are using an LSP configuration file in your network, any changes to LSPs that you make in the LSP browser are subsequently written to the configuration file when you click OK to close the browser.

Applying QoS to an MPLS Network Model

Differential Services (DiffServ) extensions can be used to apply quality-of-service constraints to your MPLS network model. To do this, you must configure QoS do the following:

- Specify traffic classes in the MPLS configuration object

- Adjust DSCP settings in the QoS configuration object

- Configure queuing schemes and profiles on the affected routers

To use different traffic classes in your MPLS network, you must first specify separate traffic trunks for the different classes in the MPLS configuration object. To do this, use Procedure 6-5 on page SPM-6-16 to create a default traffic trunk. However, instead of setting the Trunk Details attribute to Default, double-click to set the traffic profile, out-of-profile actions, and traffic class of each trunk.

To configure quality-of-service parameters, edit the Priority Queuing Profiles ⨼ DSCP Based attribute in the QoS configuration object.

Finally, you must configure the affected routers to use the correct queueing scheme and queuing profile.


Procedure 6-9   Configuring the Queuing Stream and Profile of a Router

1 Set the Queuing Scheme attribute (IP Routing Parameters ⨼ Interface Information ⨼ QoS Information)

2 Set the Queuing Profile attribute to DSCP Based.

End of Procedure 6-9

If you change the queuing scheme later, make sure you reset the queuing profile because the order of these steps is important.

Figure 6-15   Configuring QoS on an LER

Always set the Queuing Scheme before setting the Queuing Profile.
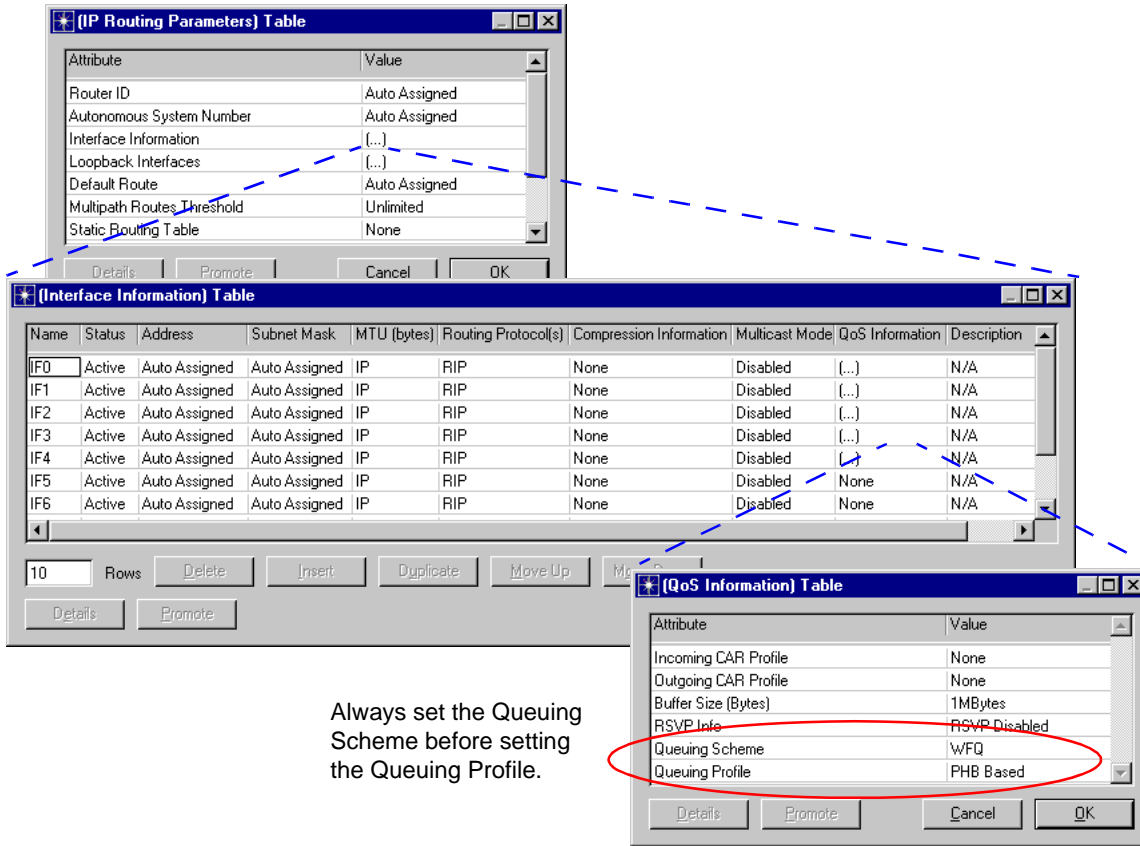
MPLS Menu Operations

The Protocols > MPLS menu enables you to configure, edit, and display MPLS features in the network topology. With the MPLS menu operations, you to streamline the MPLS configuration process. Table 6-3 lists the operations available from the Project Editor's Protocols > MPLS menu.

Table 6-3   MPLS Menu Summary

Menu Item	Description
Update LSP Details	Updates all static LSPs with label switching information.
Configure LSPs from Demands	Creates dynamic LSPs between all traffic flows.
Browse/Edit LSP Information...	Opens the LSP browser.
Import LSP Information...	Imports LSP information from files.
Display LSP Routes...	Displays the routes chosen by CR-LDP. Does not display link statistic information.
Hide all LSP Routes...	Hides LSP route display.
Show All LSPs	Displays hidden LSPs in the workspace. This operation does not display LSPs which are configured only in the LSP configuration file. To display those LSPs, use the display functions in the LSP browser.
Hide All LSPs	Hides LSPs displayed in the project workspace from view.
Clear All LSPs	Deletes all LSPs in the network and resets the traffic mapping configuration.
Deploy MPLS VPNs	
Configure Interface Status	Enables/disables MPLS protocol status on either selected or all routers.
Model User Guide	Opens this document.
End of Table 6-3	

Information for OPNET Modeler Users

The rest of this document contains information for model developers (such as OPNET Modeler users). The following sections describe the topics necessary for understanding the internal details of and interfacing to the MPLS model.

Model Architecture

Each node that can use MPLS has an IP module, which contains a dispatcher process that spawns MPLS processes. The following table lists the process models used by the MPLS model.

Table 6-4   MPLS Process Models

Process model	Description
mpls_mgr	One instance of this process is spawned by ip_dispatch on each MPLS enabled node in the network. It represents the forwarding component of MPLS and the forwarding control plane.
	When the IP module of an LSR receives labeled packets or packets with matching FEC descriptions, it performs no IP processing on the packet. Instead, the packet is re-directed to the mpls_mgr process for MPLS forwarding.
	mpls_mgr uses ILM (incoming label map) and FTN (FEC to NHLFE maps) to forward packets.
mpls_ldp_mgr	Implements the LDP control plane in the LDP module of all routers. This process is the dispatcher for the mpls_discovery_mgr, mpls_session_mgr, and mpls_lsp_mgr processes.
mpls_discovery_mgr	Sends periodic broadcast hello messages over UDP to discover MPLS-enabled neighbor routers.
mpls_session_mgr	Negotiates, opens, and maintains TCP sessions to neighboring LDP routers. The TCP sessions are used to exchange label maps. This process is based on RFC 3036.
mpls_lsp_mgr	Controls the exchange-to-label mappings between LDP peers. Communication with LDP peers occurs through the session established by the mpls_session_mgr process. This process is based on RFC 3036.
End of Table 6-4	